Real Time Traffic Capabilities Evaluation of a Hybrid Testbed for WiMAX Networks with Smart Antenna Support

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Abstract. The ever-increasing adoption of the Internet and multimedia services rise new challenges for the next generation network solutions, especially on the wireless ones. WiMAX is one of the new technologies developed for broadband wireless networks. It offers high data rate services while providing high flexibility for the radio resource management. Adding smart antenna support and developing new scheduling and routing algorithms for wireless mesh networks based on WiMAX technology will recommend it as a very attractive solution for the next generation wireless networks. In this paper a basic simulation testbed for a WiMAX network with smart antenna support is proposed. It is based on OPNET simulation tool and uses the System-in-the-Loop function to interconnect the simulated system with a real network, for a better functional and performance evaluation. The advantage of using smart antennas is illustrated by the simulation results.

Keywords: WiMAX networks, smart antenna, OPNET, System-in-the-Loop.

1 Introduction

In the last years wireless communications had an exponential growth, with a huge social end economical impact. The current services require high data rates at the radio interface which pushed forward the development of high capacity wireless technologies, such as WiFi, WiMAX or LTE. The throughput increase on the radio interface was made possible by the development of new complex techniques in signal processing at the physical level, such as turbo coding, MAQ modulation, OFDMA, MIMO. However, last-mile access network technologies represent a significant congestion spot between the high-capacity core backbone network and the high-capability terminal equipments. In order to reduce these requirements new solutions to exploit these technologies need to be developed. The IEEE 802.16 technology and WiMAX based sytems constitute an attractive solution for metropolitan and rural areas, [10]. Recently, advances made at physical layer introducing directional smart antennas showed a possible increase in performance, while keeping the transmitting power at the same level as for omni-directional antennas case.

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In this paper a basic simulation testbed for a WiMAX network with smart antenna support is proposed. It is based on OPNET simulation tool and uses the System-in-the-Loop function to interconnect the simulated system with a real network, for a better functional and performance evaluation [1]. The testbed was developed in the framework of the SMART-Net FP7 project [3]. The SMART-Net project defined an architecture and then designed and developed a Wireless Mesh Network solution mainly based on WiMAX and WiFi technology, by introducing smart antennas support in WiMAX. The project proposed efficient scheduling and routing algorithms, to enhance the capacity and to provide scalability, reliability and robustness for such a system [2],[5]. Inside this project, both performance evaluation based on simulations and real life testbed have been conducted. In order to combine the capabilities of the two techniques, cooperation between the two frameworks has been achieved by coupling them using the technique called System- in-the-loop, [1]. This paper presents a basic simulation testbed for evaluating the smart antennas integration on standard OPNET WiMAX nodes and also for evaluating the smart antennas capabilities [4]. It represents a starting point for the development of a combined simulation model-HW model for the SMART-Net proposed system. Adding smart antennas support in OPNET WiMAX nodes was the first step in starting integrating the already developed components of the SMART-Net OPNET system model.

This paper is organized as follow. The second section is a short description of the SMART-Net system and of the smart antennas. The third section is dedicated to the testbed. It is presented its structure and the simulation scenarios. The fourth section provides the simulation results. The last section presents conclusions and guidelines for future work.

2 Smart-Net System

2.1 Smart-Net Features

Smart-Net solution for Broadband Wireless Access is based on a system architecture which consists on multimode devices with smart antennas support. These devices are interconnected in a partial mesh topology which has a central point, Smart Gateway (SMG), acting as gateway linked to the backhaul networks. The other nodes of the network are either SMART Stations (SMS) or SMART Relays (SMR). A SMR is an operator's equipment which is specifically used to forward data traffic to the users, allowing coverage extension and cooperative diversity, while a SMS is a subscriber station that also enables data transfer for other users based on the service provider policy [3], [10].

System capacities can be significantly improved by introducing multi-hop capabilities and mesh networking in wireless access networks. The use of relay stations results in a signal to noise ratio enhancement, allowing obtaining higher throughput and coverage while reducing the device transmitting power. Indeed the user station does not have to communicate directly with the central station and then, by minimizing the transmit power levels, co-channel interference can be reduced [8], [9].

Using omnidirectional antennas in wireless networks create inherently interference, which decrease the capacity of the system. A significant increase in capacity is obtained by using smart antennas. They feature a directivity that can be controlled by higher levels protocols (Layer 2, Layer 3) in the network node, allowing its orientation towards the destination node and thus reducing interference. In the same time, directional antenna can be used to increase radio coverage.

The Smart-Net project introduced smart-antenna support on WiMAX equipments and developed some algorithms for scheduling and routing in a multihop relay based WiMAX mesh network [2], [6]. To validate the proposed solutions two testbeds were developed during the project. A real life testbed consisting of Wimax equipments with smart antennas installed. The WiMAX equipments used in the testbed are produced by Thales Company and the smart antennas are produced by Plasma Antennas Company. Both are members of the Smart-Net project. In parallel, a simulated testbed was developed using the OPNET network simulator [4]. The smart antennas were modeled in the OPNET and integrated in WiMAX nodes. Experiments were performed to evaluate the smart antennas and the proposed algorithms.

Also, it was proposed by the project to perform experiments by combining the real life and simulated testbeds in order to obtain a more complex experimental system. For the testbeds interconnection the System-in-the-Loop (SITL) function provided by OPNET was used. Such approach is presented in [7]. OPNET and SITL are used to evaluate wireless tactical networks. Two simulated tactical units communicate via simulated wireless link. Two real life tactical units are interconnected with the simulated network via SITL. The capacity of the simulated tactical units to exchange real traffic, generated by a military application installed on the real life unit, while they move on a predefined trajectory over a virtual terrain, is evaluated. In this paper a similar approach is used to evaluate the smart antennas integration on standard WiMAX node and the smart antennas performances related to the standard omnidirectional ones.

2.2 Smart Antennas

Smart antenna systems intelligently combine multiple antenna elements with signal-processing capability to optimize its radiation and reception patterns automatically [3]. They have a certain number of high gain beams with low sidelobes, which minimize interference both on transmit and receive, without using complex adaptive nulling algorithms. Low sidelobe multi-beam antennas have the advantage over adaptive systems in that they suppress a very large number of interferers in a consistent, predictable way. Adaptive systems are limited by their degrees of freedom (e.g. number of radios), their adaptation time and might not work well (i.e consistently) when the signal of interest is at the edge the receiver's sensitivity. However, they potentially have the advantage of allowing the suppression of interfering signals that are close in angle (within a beamwidth) to the source-of-interest.

When receiving, smart antennas can maximize the sensitivity in the direction of the desired signal and minimize the sensitivity towards interfering sources.

For reasons of cost and consistency of performance common smart antennas are switched or selectable multi-beam antennas, requiring only a single radio. These antennas have multiple fixed beams and the system switches very rapidly between these beams. A simultaneous coverage of these beams is also possible, for broadcast purposes, in the form of an omnidirectional or a sectoral beam.

For the SMART-Net project, two types of multi-beam antennas, capable of WiMAX operation, have been designed and implemented [2], [3].

- An active, 12 beam cylindrical array antenna with omni-mode
- A passive 9 beam planar array antenna with sectoral mode.

The active 12-beam cylindrical antenna with it 360° coverage has been selected to be most suitable for mesh and nomadic Point to Multipoint operation, with typical ranges up to 20 km, depending on the modulation rate. The passive 9 beam planar antenna, with its narrow beams has been selected to be most suitable for medium range backhaul and relay operations. A representation of both antennas, suitable for inclusion within OPNET, has also been provided, but as *simulated* data.

Besides the multibeam antennas, a switching algorithm is used to choose the appropriate beam among the available antenna beams. This algorithm is based on a learning interval in which, based on SINR, the best beam is chosen for each destination. Based on the decision took by the selection algorithm, when a smart node (a node equipped with smart antennas) needs to communicate with another smart node, the beam with the best SINR is used. Because the best beam is decided in the learning phase, the switch operation is very fast, a few nanoseconds. Some performance degradation is expected in the mobile nodes case, because the learning interval lasts a few milliseconds. In this paper only evaluation of smart antenna on fixed WiMAX nodes is presented. For mobile nodes the smart antenna integration is not ready.

3 Real Time Simulation of Smart Antenna Using the Smart-Net Simulated Testbed

3.1 Simulated Testbed Infrastructure

The testbed infrastructure consists of a simulated WiMAX network which is interconnected with real devices in order to introduce real time traffic in the simulation (figure 1). The System-in-the-Loop is an OPNET facility which allows real time communication between real and simulated parts of the networks within the simulation loop [1], [7]. By using SITL, OPNET simulation exchanges the packets between simulations and real networks in real-time. The SITL gateway represents an external device through which the simulation exchanges the packets, where the WinPcap library is used to route those packets selected by user defined filter, from an Ethernet network adaptor, to the simulation process.

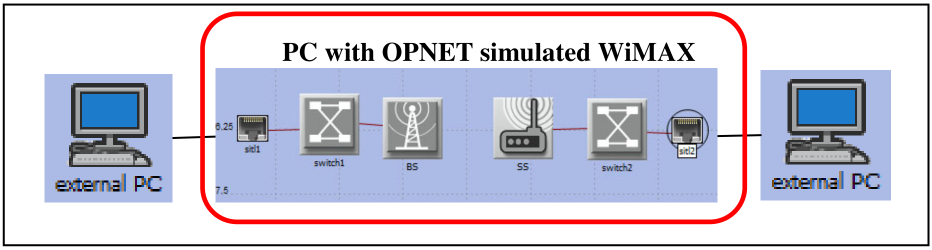


Fig. 1. Testbed infrastructure: a simulated WiMAX network interconnected with external devices via OPNET System-in–the-Loop functionality

The simulation runs in real-time and exchanges packets with the external hardware via an Ethernet link. The requirement of using Ethernet link between the real devices and the SITL gateway introduces limitation in developing joint real and simulated wireless network scenarios. Joint scenarios for evaluating scheduling and routing algorithms for wireless mesh networks are not possible with SITL. The interconnection scenarios were limited at evaluating the effects on real time traffic while crossing the interconnected testbeds.

There are three main simulation topologies for using the SITL module:

- real-to-real (communication between real devices over simulated network)
- sim-to-sim (communication between simulated devices over real network)
- sim-to-real (communication between real and simulated devices).

3.2 Simulated Scenarios

The detailed view of the simulated WiMAX network is presented in figure 2. A real-to-real SITL topology is used for these scenarios. It consists of a single WiMAX link, between a Base Station and a fixed Subscriber Station, which is concatenated with Ethernet links at both ends. These Ethernet links are used to interconnect, via SITL gateways, the WiMAX simulated network with the external stations which are both acting as real time streaming server and player. The smart antennas were installed on the simulated WiMAX nodes. Introducing smart antenna support on standard WiMAX nodes requires modifying the radio transceiver pipeline stages. The beam selection algorithm was introduced in the pipeline stages together with the 12 beam cylindrical array and 9 beam planar array antenna models.

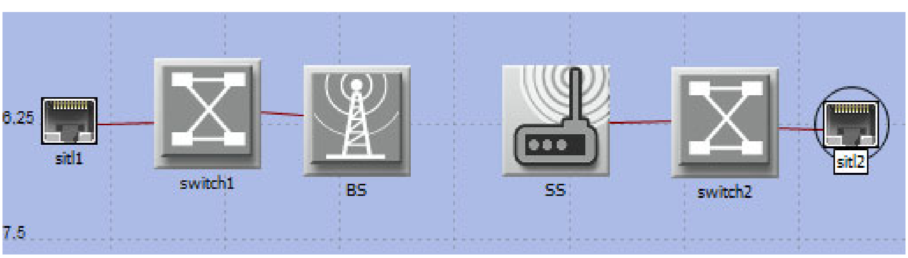


Fig. 2. The OPNET simulated scenario. The Base Station and a fixed Subscriber Station are each connected to separate SITL gateways through Ethernet switches.

Given the complexity of the components, the experiments presented in this paper focused on functional evaluation. Further simulations need to be performed in order obtain precise performance evaluation for the smart antenna in Smart-Net system.

The following two scenarios were created in order to evaluate the smart antennas integration in standard WiMAX nodes using the OPNET SITL tool. The first one uses the topology given in figures 1 and 2 with standard WiMAX nodes (with omnidirectional antennas). It is used to evaluate the SITL behavior and as a reference for the second scenario. The second one uses the same topology but WiMAX nodes with smart antenna support (modified transceiver pipeline stages). This scenario is used to evaluate the smart antennas behavior and their performances related to the omnidirectional case.

4 Simulation Results

As mentioned in the previous section two scenarios were proposed for evaluating simulated smart antennas integration on WiMAX nodes. Both scenarios are based on real time flows which are sent through the simulated WiMAX network using the OPNET SITL functionality. This approach allows the evaluation of the simulated system model to transport real time traffic flows, like video streaming, interactive voice. More realistic evaluation, closer to a real life one is obtained in [9].

In the first scenario, a movie with a rate around 2.5 Mbps is streamed from the streaming server through the simulated WiMAX link. On the same link and in the same direction (downlink) it is transmitted a noise UDP traffic with the rate of 5Mbps. All the flows are transmitted as Best Effort. A total of around 7.5 Mbps throughput is transmitted on the downlink. The WiMAX physical parameters are: 20MHz bandwidth, 2048 subcarriers, 10.94 kHz subcarrier frequency spacing, symbol duration of 102,86 ms, frame duration of 5ms [10]. The antenna gain is set at 15 dB. Adaptive modulation and coding is used on the physical interface.

Both scenarios have been repeated by varying the distance between the BS and SS. Also the SS orientation, related to the BS which is fixed, is changed. This is useful for the second scenario when smart antennas are used. By changing the orientation, the functionality of the beam selection algorithm is evaluated. If it chooses the right beam, this will be reflected in the link quality. The simulation duration is set at 5 minutes for each experiment. The first scenario results are shown in figure 3. It illustrates the throughput on the WiMAX link in each selected experiment. For each experiment standard omnidirectional antenna was used. As it was expected the capacity of the WiMAX link decreases while the distance between nodes is increased. On figure 3, the curve with the smallest throughout correspond to the case when we have the biggest distance between nodes. The WiMAX capacity decrease is illustrated also by the perceptual evaluation of the movie quality.

For the second scenario the same parameters have been used and moved the SS in the same positions as those used in the first scenario. The planar 9 multibeam smart antennas were installed on WiMAX nodes. In all experiments performed the WiMAX link capacity was similar or better than in case of omnidirectional antenna. This assertion is sustained by the results illustrated in figure 4 and figure 5. Figure 4 presents the throughput obtained in the omni-beam and smart antenna case when the BS and SS are at the same distance and in the same positions. The higher throughput curve corresponds to the smart antenna scenario. For small distances between the BS and SS node the throughput is the same. When the distance is increased the difference between the throughputs obtained in each case is increased – the higher throughput being obtained when using smart antennas.

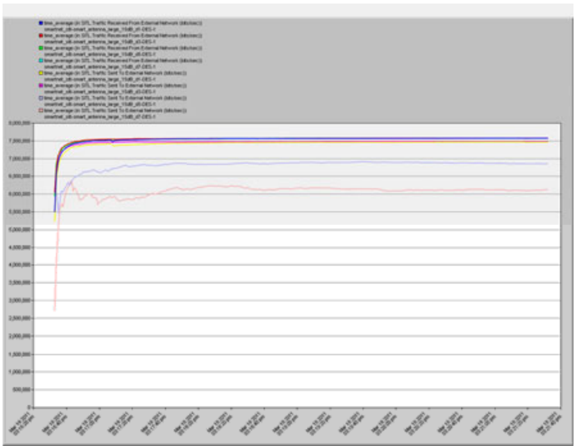


Fig. 3. First scenario results: The capacity of the WiMAX link decreases while the distance is increased

Because the direction of the WiMAX link was modified while moving the SS node and in all cases the link quality was good, it means that the beam selection algorithm is working correctly. To better evaluate the selection algorithm the following experiments were performed in the second scenario: the SS node was moved in several positions situated on a circle centered in the BS node. The link capacity and movie quality remained the same for all experiments. This showed that the smart antennas are able to choose the right beam for each case, offering better link quality due to better signal to interference ratio obtained when a narrow beam is used.

The real video flows transmitted through the simulated network offered us the possibility to perceptually evaluate the smart antenna benefits. Figure 5 presents a capture from the received movie in each of the two mentioned experiments. A frame with a poor perceptual video quality, obtained for the standard omni-antenna, is presented in figure 5a. Figure 5b shows a video frame taken in the case when a similar simulated topology (the same positions for BS and SS) as the one used to obtain figure 5a was used. The perceptual movie quality decreased less when smart antennas were used. From these results we can say that the WiMAX nodes with smart antennas present superior performances comparing with the standard ones. Some performance degradation could be obtained when the nodes are situated at border between two beams. A larger set of experiments must be performed in order to "catch" and illustrate this degradation.

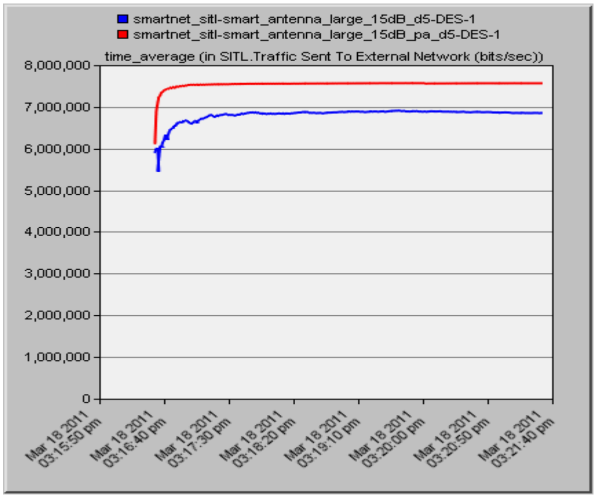
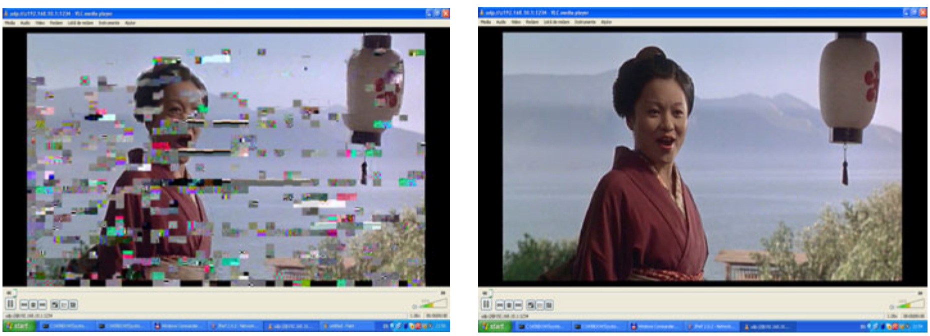


Fig. 4. Wimax throughput for the omni-beam and smart-antenna cases, for the same distance between the BS and SS nodes and the same nodes positions



a) b)

Fig. 5. Perceptual illustration of the smart antenna benefits. Received movie snapshot for: a) omnidirectional antenna. b) smart antenna.

5 Conclusions

This paper presents a basic simulation testbed used to evaluate beam selection algorithm and switched beam antennas performances for WiMAX technology. The discussed solutions are proposed in the Smart-Net project. The presented testbed was built on a OPNET (version 14.5) Platform and it uses OPNET SITL module to interconnect the simulated network with real life devices. Even if SITL module has some limitations, which restrict its use for wireless mesh networks, it proved to be very useful for performance evaluations, because it allows introducing real time traffic in the simulated network, and then analyzing how it is affected while passing through the simulated devices.

For the future, the simulated testbed will be developed by implementing with the presented smart nodes the wireless mesh network proposed in Smart-Net project. Then, the proposed algorithms, for scheduling and routing in this WiMAX based mesh network with smart antenna support, will be evaluated.

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References

1. OPNET 14.5 PL0 documentation, `http://www.opnet.com/support`
2. Wendt, S., Abdallah, A., Hayes, D., Foul, T.A., Borcoci, E.: Project Deliverable, D3.3a: Preliminary description of cross layer optimization. ICT European FP 7 SMART-Net project
3. Wendt, S., Kharrat-Kammoun, F., Borcoci, E., Cacoveanu, R., Lupu, R., Hayes, D.: Project Deliverable, ID2.4b: Network Architecture and System Specification. ICT European FP 7 SMART-Net project, internal WP2 deliverable (October 2010)
4. Kammoun, F.K., Meddour, D., Baraev, A., Rasheed, T., Hamadani, E., Tonnerre, A., Borcoci, E., Enescu, A., Ciochina, S.: Project Deliverable, D4.1: Large Scale Simulation Testbed Specifications. ICT European FP7 SMART-Net project Deliverable (January 2009)
5. Baraev, A., Rasheed, T., Selva, B., Tonnerre, A., Wendt, S., Hamadani, E., Borcoci, E., Badoi, C., Cacoveanu, R.: Project Deliverable, D4.3b: Assessments on System Level Implementations and Simulations, ICT European FP 7 SMART-Net project (May 2010)
6. Mostafavi, M., Hamadani, E., Vural, S., Borcoci, E., Constantinescu, M., Niculescu, D., Rasheed, T., Riggio, R., Gomez, K., Baraev, A.: Project Deliverable, D3.2b: Performance analysis of efficient routing protocols for multimode mesh networks (October 2010)
7. Mohorko, J., Fras, M., Čučej, Ž.: Real time "system-in-the-loop" simulation of tactical networks. In: 16th International Conference on Software, Telecommunicati ons and Computer Networks, SoftCOM 2008, September 25-27, pp. 105–108 (2008)
8. Kortebi, R., Meddour, D.-E., Gourhant, Y., Agoulmine, N.: SINR-Based Routing in Multi-Hop Wireless Networks to Improve VoIP Applications Support. In: IEEE Proceeding of CCNC 2007, Las Vegas, USA (2007)
9. François, J., Bertrand, M., Meddour, D.-E.: Video Streaming Experiment on Deployed Ad hoc Network. In: The Proceeding of the IEEE International Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities (TridentCom), Orlando, USA (May 2007)
10. IEEE Standard 802.16-2004, Air Interface for Fixed Broadband Wireless Access Systems